



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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| <b>(21) International Application Number:</b> PCT/GB00/00521<br><b>(22) International Filing Date:</b> 17 February 2000 (17.02.2000)<br><b>(30) Priority Data:</b><br>9903474.6 17 February 1999 (17.02.1999) GB<br><b>(60) Parent Application or Grant</b><br>UNIVERSITY OF NEWCASTLE [/]; (). RAMSHAW, Colin [/]; (). JACHUCK, Roshan, Jeet, Jee [/]; (). RAMSHAW, Colin [/]; (). JACHUCK, Roshan, Jeet, Jee [/]; (). HARRISON GODDARD FOOTE ; ().   |           | <b>Published</b>  |
| <b>(54) Title:</b> ROTATING SURFACE OF REVOLUTION REACTOR WITH FEED AND COLLECTION MECHANISMS<br><b>(54) Titre:</b> SURFACE PIVOTANTE D'UN REACTEUR A REVOLUTION AVEC DES MECANISMES D'ALIMENTATION ET DE COLLECTE<br><br><b>(57) Abstract</b><br><p>A reactor including a rotatable disc (3) having a trough (13) in an upper surface (5) thereof. Reactant (15) is supplied to the trough (13) by way of a feed (4), the disc (3) is rotated at high speed, and the reactant (15) spills out of the trough (13) so as to form a film (17) on the surface (5). As the reactant (15) traverses the surface (5) of the disc (3), it undergoes chemical or physical processes before being thrown from the periphery of the disc (3) into collector means (7).</p> <b>(57) Abrégé</b><br><p>L'invention concerne un réacteur comprenant un disque pivotant (3) dont la surface supérieure (5) présente un bac (13). Un réactif (15) est amené vers ce bac (13) par l'intermédiaire d'un dispositif d'alimentation (4), le disque (3) pivotant à une vitesse élevée et le réactif (15) débordant du bac (13) de manière à former une pellicule (17) sur ladite surface (5). Au fur et à mesure qu'il traverse cette surface (5) du disque (3), le réactif (15) subit des processus chimiques ou physiques, avant d'être éjecté de la périphérie du disque (3) jusque dans un organe collecteur (7).</p> |           |   |

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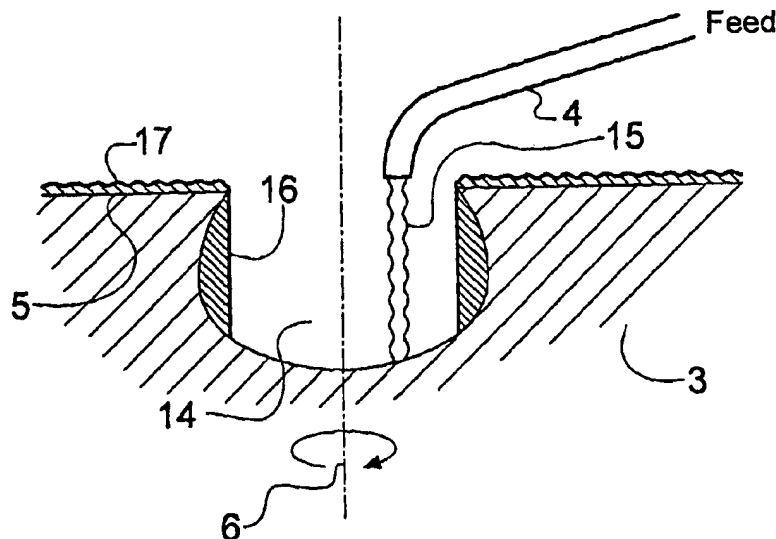
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| (21) International Application Number: PCT/GB00/00521<br>(22) International Filing Date: 17 February 2000 (17.02.00)<br>(30) Priority Data:<br>9903474.6 17 February 1999 (17.02.99) GB<br>(71) Applicant (for all designated States except US): UNIVERSITY OF NEWCASTLE [GB/GB]; 6 Kensington Terrace, Newcastle Upon Tyne NE1 7RU (GB).<br>(72) Inventors; and<br>(75) Inventors/Applicants (for US only): RAMSHAW, Colin [GB/GB]; 20 High View, Ponteland, Newcastle Upon Tyne NE20 9ET (GB). JACHUCK, Roshan, Jeet, Jee [IN/GB]; 10 Marcross Close, Abbey Farm, North Walbottle, Newcastle upon Tyne NE1 7RU (GB).<br>(74) Agent: HARRISON GODDARD FOOTE; Tower House, Merriion Way, Leeds LS2 8PA (GB). |  | (81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).<br><br>Published<br>Without international search report and to be republished upon receipt of that report. |   |

(54) Title: ROTATING SURFACE OF REVOLUTION REACTOR WITH FEED AND COLLECTION MECHANISMS



(57) Abstract

A reactor including a rotatable disc (3) having a trough (13) in an upper surface (5) thereof. Reactant (15) is supplied to the trough (13) by way of a feed (4), the disc (3) is rotated at high speed, and the reactant (15) spills out of the trough (13) so as to form a film (17) on the surface (5). As the reactant (15) traverses the surface (5) of the disc (3), it undergoes chemical or physical processes before being thrown from the periphery of the disc (3) into collector means (7).

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**Description**

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**ROTATING SURFACE OF REVOLUTION REACTOR WITH FEED AND  
COLLECTION MECHANISMS**

The present invention relates to a rotating surface of revolution reactor provided with various feed and collection mechanisms for input and output products.

The invention makes use of rotating surfaces of revolution technology (hereinafter RSORT) (commonly known as spinning disc technology).

The spinning disc concept is an attempt to apply process intensification methods within the fields of heat and mass transfer. The technology operates by the use of high gravity fields created by rotation of a disc surface causing fluid introduced to the disc surface at its axis to flow radially outward under the influence of centrifugal acceleration in the form of thin often wavy films. Such thin films have been shown to significantly improve the heat and mass transfer rates and mixing. The technology was developed for typical heat and mass transfer operations such as heat exchanging, heating, cooling and mixing, blending and the like, for example as disclosed in R J J Jachuck and C Ramshaw, "Process Intensification: Heat transfer characteristics of tailored rotating surfaces", Heat Recovery Systems & CHP, Vol. 14, No 5, p475-491, 1994.

More recently the technology has been adapted for use as a reacting surface for systems which are heat and mass transfer limited, for example for the reaction of substrates which are highly viscous during at least a stage of the reaction and cause problems in achieving good mixing and product yields.

Boodhoo, Jachuck & Ramshaw disclose in "Process Intensification: Spinning Disc Polymeriser for the Manufacture of Polystyrene" the use of a spinning disc apparatus in which monomer and initiator is reacted by conventional means to provide a pre-polymer which is then passed across the surface of a spinning disc at elevated temperature providing a conversion product in the form of polymerised styrene.

EP 0 499 363 (Tioxide Group Services Limited) discloses another use for spinning disc technology in photo catalytic degradation of organic materials such as hydrocarbons. A solution of salicylic acid and titanium dioxide catalyst was passed across the surface of a rotating disc and irradiated with ultra violet light.

5                   These publications therefore disclose the use of spinning disc technology for heating and mass transfer in inert and reactive systems.

10                   GB 9903474.6 (University of Newcastle), from which the present application claims  
5                   priority and the disclosure of which is hereby incorporated into the present application by reference, describes the use of RSORT in the conversion of a fluid phase substrate by dynamic heterogeneous contact with an agent. In this application,  
15                   it is described how it has surprisingly been found that spinning disc technology may be further adapted to apply process intensification methods not only within the fields  
20                   of heat and mass transfer but also within the field of heterogeneous contacting. Furthermore, it is described how it has surprisingly been found that the quality of the product obtained is of higher quality than that obtained by conventional processing having, for example, a higher purity or, in polymers, a narrower molecular distribution.

15                   In addition to this, spinning disc technology can be used to obtain products not readily obtainable by other technology.

20                   According to the present invention, there is provided a reactor apparatus including a support element adapted to be rotatable about an axis, the support element having  
30                   generally opposed first and second surfaces, feed means for supplying at least one reactant to the first surface of the support element and collector means for collecting product from the first surface of the support element, characterised in that the first surface includes a trough into which the at least one reactant is supplied by the feed means.  
35                   25

40                   It is to be understood that the term "reactant" is not limited to substances which are intended to undergo chemical reaction on the surface of the support element, but also includes substances which are intended to undergo physical or other processes such  
30                   as mixing or heating. Similarly, the term "product" is intended to denote the substance or substances which are collected from the first surface of the support element, whether these have undergone chemical or physical processing or both. In  
45                   addition, although it is envisaged that most reactants and products will be in the liquid phase, the apparatus can be used with any suitable fluid phase reactants and  
35                   products, including combinations of liquid, solid and gaseous reactants and products. For example, solid phase substances in substantially free-flowing particulate form can have macroscopic fluid flow properties.

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The depth of the trough may be selected in accordance with reaction requirements. For example, for photochemical reactions in which UV light is shone onto the reactant, it is preferred for the trough to be relatively shallow, for example having a depth of the same order of magnitude or within one order of magnitude as the expected thickness of a film of reactant formed across the first surface of the support element when rotating at an appropriate speed.

An RSORT apparatus (commonly known as a spinning disc reactor) generally includes within a conversion chamber a rotating surface or an assembly of a plurality of these which is rotated about an axis to effect transfer of one or more reactants from the axis preferably radially across the rotating surface.

An RSORT apparatus as hereinbefore defined comprising a rotating surface as hereinbefore defined has a number of advantageous constructional features according to the present invention.

The axis of rotation of the rotating surface or support member may be substantially vertical, in which case gravity tends to pull reactants downwardly with respect to the surface or support member. This may be advantageous with less viscous reactants. Alternatively, the axis of rotation may be generally horizontal, which can achieve improved mixing of reactants provided that these are appropriately retained on the first surface of the support member.

Any suitable feed means may be provided to feed the at least one reactant onto the rotating surface. For example, the feed means may comprise a feed distributor in the form of a "shower head", a "necklace" of outlets or a simple, preferably adjustable, single point introduction such as a "hose-pipe type" feed means. Preferably, the feed means comprises a feed distributor having a plurality of uniformly spaced outlets for the at least one reactant on to the rotating surface as hereinbefore defined. The feed means may also include means for applying UV, IR, X-ray, RF, microwave or other types of electromagnetic radiation or energy, including magnetic and electric fields, to the reactants as they are fed to the trough, or may include means for applying vibration, such as ultrasonic vibration, or heat.

The feed means may be provided at any suitable position with respect to the rotating surface which allows feed of the reactant. For example, the feed means may be

axially aligned with the rotating surface for axial feed. Alternatively, the feed means may be positioned such that the feed is spaced from the axis of the rotating surface. Such a position may lead to more turbulence and an enhanced mixing effect.

In one embodiment, feed means may comprise a single feed to the trough which is preferably situated on or co-axial with the axis of rotation of the rotating surface. In this embodiment, reactant flows from the feed outlet into the trough and is subsequently spread out of the trough on to the rotating surface by centrifugal force. In a preferred embodiment, the rotating element as hereinbefore defined comprises a trough situated on the axis of rotation.

The trough as hereinbefore defined may be of any suitable shape such as continuous or annular. For example it may have a continuous concave surface comprising part of a sphere, such as a hemispherical surface, or it may have an inner surface joined to the rotating surface by at least one connection wall or at least two, in the case where the trough is annular. The inner surface and connection wall may be of any form which allows the function of a trough to be fulfilled. For example the inner surface may be parallel to the rotating surface or concave or convex. The connection wall may comprise a single circular or ovoid wall or a plurality of straight walls. The walls may diverge or converge towards the rotating surface.

Preferably, a single circular wall is provided which converges towards the rotating surface to form an undercut trough. This shape generates a reservoir which enhances a circumferential distribution of the reactant flow. Alternative means for forming an undercut trough are also envisaged. For example, where the trough is generally annular in shape, an outer wall may be provided as above, and an inner wall having any suitable shape may serve to define an inner edge to the trough. The undercut portion of the trough should generally be provided as an outer wall so as to help prevent uncontrolled egress of reactant from the trough to the first surface under the influence of centrifugal force as the support element is rotated.

Advantageously, a matrix may be provided in the trough so as to help reactant present in the trough to rotate with the support element, thereby helping to achieve substantially uniform flow from the trough across the first surface. The matrix may be in the form of a plug of fibrous mesh, such as metal or plastics wool, or may take the form of a plurality of projections which are secured to an inner surface of the trough. Other matrix means will be apparent to the skilled reader. In some



embodiments, the matrix is manufactured of a material which is inert with respect to the at least one reactant or the product and which is not significantly affected by temperature and other variable process conditions. Alternatively, the matrix may be made of a material which does interact with the at least one reactant or the product, such as a heterogeneous catalyst (e.g. nickel, palladium or platinum or any suitable metal or alloy or compound thereof). Where the matrix is made out of an electrically conductive material, it may be possible to supply an electric current therethrough and thus to provide heating means for heating the at least one reactant within the trough.

In a further embodiment, there may be provided a plurality of feeds adapted selectively to supply one or more reactants to a plurality of troughs formed in the first surface. For example, where the support element is generally disc-like and has a substantially central axis of rotation, there may be provided a first central trough centred on the axis of rotation and feed means for supplying at least one reactant to the first trough, and at least one further trough, preferably also centred on the axis of rotation and having an annular configuration, the at least one further trough being provided with feed means for supplying a second reactant, which may be the same as or different from the first reactant, to the at least one further trough. It will be apparent to the skilled reader that a plurality of troughs may be provided in a similar manner on support elements with shapes other than generally disc-like.

By providing a plurality of troughs and feeds, a sequence of reactions can be performed across the first surface of the support element. For example, two reactants may be supplied to the first trough in which some mixing and reaction will take place. As the support element rotates, the reactants will spread from the first trough to the first surface of the support element, where further reaction and mixing takes place, and thence into a second annular trough concentric with the first trough. A third reactant may then be supplied to the second trough, and further mixing and reaction will take place as the third reactant and the two initial reactants and any associated product are spread from the second trough onto the first surface of the support element for further mixing and reaction. Because the direction of travel of the reactants and products is outwards from the axis of rotation, a controlled series of reactions can be carried out across the first surface of the support member.

In some embodiments, one of the reactants may be a liquid phase component and another may be a gaseous phase component. In these embodiment, the rotating support member is advantageously contained within a vessel so as to allow the

5 concentration of the gaseous phase component in the vicinity of the surface to be  
controlled. The liquid component may be fed to the surface of the disc as described  
above, and the gaseous component supplied to the vessel. A rotary impeller or fan or  
10 similar device may be mounted close to the rotating surface and driven so as to suck  
5 the gaseous phase component from a region surrounding the periphery of the rotating  
surface towards the centre of the rotating surface while the liquid phase component  
travels from the centre of the surface towards its periphery due to the rotation of the  
rotating surface. Where, for example, the support element is a disc, the impeller or  
15 fan may take the form of a generally disc shaped structure mounted coaxially with the  
support element and close thereto. A surface of the impeller or fan facing the  
rotating surface of the support element may be provided with blades or vanes such  
20 that rotation of the impeller or fan serves to suck the gaseous phase component from  
a periphery of the surface and the impeller or fan towards the centre of the surface.  
By providing a counter-current flow of the gaseous and liquid phase components,  
15 heat or mass transfer between the components is much improved, since the  
concentration of unreacted liquid phase reactant is lowest at the periphery of the disc,  
25 and therefore benefits from a high concentration of the gaseous phase component so  
as to ensure full reaction.

20 Any suitable collection means may be provided for collection of the product as it  
leaves the rotating surface at its periphery. For example, there may be provided a  
receptacle in the form of a bowl or trough at least partially surrounding the rotating  
element or other fixed part of the apparatus. The collection means may additionally  
30 comprise a deflector positioned around the periphery of the rotating surface to deflect  
product into the collection means. The deflector is preferably positioned at an acute  
35 angle to the rotating surface.

The components of the collection means, such as the bowl or trough or deflector,  
40 may be coated or otherwise provided with a heterogeneous catalyst appropriate to the  
reactants being reacted on the support element, or may even consist entirely of a  
material which acts as a heterogeneous catalyst. Furthermore, the components of the  
collection means may be heated or cooled to a predetermined temperature so as to  
45 enable control over reaction parameters, for example by serving to halt the reaction  
between reactants as these leave the first surface in the form of product. Feed means  
35 for supplying a reactant to the product leaving the first surface may also be provided.  
For example, there may be provided feed means for feeding a quenching medium to  
product in the collection means so as to halt chemical or other reactions between  
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5 reactants when these have left the first surface.

10 The collection means may further comprise outlet means of any suitable form. For example, there may be a single collection trough running around the periphery of the disc or a collection bowl partially surrounding the rotating element.

15 Outlet means may also be provided in the collection means and these may take the form of apertures of any size and form situated at any suitable position of the collection means to allow egress of the product. In one preferred embodiment, the outlet means are situated to allow vertical egress of the substrate in use.

20 Alternatively, the collection means may comprise an outer wall provided at the periphery of the support element so as to prevent product from being thrown from the first surface, and at least one pitot tube which extends into the product which is restrained at the periphery of the support element by the outer wall. The outer wall may converge generally towards the axis of rotation of the support member so as better to retain product while the support element is undergoing rotation, although other wall configurations, such as generally parallel to or divergent from the axis of rotation may also be useful.

25 Embodiments of the present invention may include multiple support elements, which may share a common axis of rotation and which may be mounted on a single rotatable shaft, or which may be provided with individual rotatable shafts. The collection means associated with any given support element may be connected to the feed means associated with any other given support element so as to link a number of support elements in series or parallel. In this way, a reaction may be conducted across a number of support elements in series or parallel. The collection means of a first support member may be directly connected to the feed means of a second support member, or may be connected by way of a processing unit such as a pump, extruder, heater or heat exchanger or any other appropriate device. This is especially useful when dealing with viscous products, such as those which are obtained in polymerisation reactions, since the viscous product of a first support element may be processed so as to acquire more favourable physical characteristics before being used as the reactant feed for a second support element.

30 For example, where the collection means comprises an outer wall on the first surface of the support element as described above, a number of support elements may be

5 coaxially mounted on a single rotatable shaft so as to form a stack of support  
elements. A reactant feed is led to the trough of a first support element, and a  
10 collector in the form of a pitot tube has its tip located near the first surface of the first  
support element in the vicinity of the wall so as to take up product from this region.  
5 An end of the pitot tube remote from the tip is led to the trough of a second support  
element so as to allow the product of the first support element to serve as the reactant  
for the second support element, thereby allowing a number of reactions to take place  
15 in series. Alternatively, a number of parallel feeds may supply the same at least one  
reactant simultaneously to the troughs of a number of support elements and a number  
20 of parallel pitot tube collectors may gather product from a peripheral region of each  
support element, thereby allowing a reaction to take place across a number of support  
elements in parallel.

15 It is also envisaged that product collected from the periphery of a support element  
may be recycled as feed for that support element. This is useful for processes  
requiring an extended contact time for the reactants. The product may be fully or  
25 only partially recycled, depending on requirements.

20 Reference herein to a rotating surface is to any continuous or discrete planar or three  
dimensional surface or assembly which rotates approximately or truly about an axis,  
30 and preferably is reference to an approximate or true rotating surface of revolution.  
An approximate rotating surface of revolution may comprise an asymmetric axis  
and/or deviation in the surface body and/or circumference creating an axially or  
radially undulating surface of revolution. A discrete surface may be in the form of a  
35 mesh, grid, corrugated surface and the like.

40 Reference herein to a substantially radially outward flowing film as hereinbefore  
defined is to any fluid film which may be created by dynamic contact of the fluid  
phase reactant and the rotating surface as hereinbefore defined, suitably the fluid  
30 phase reactant is contacted with the rotating surface at any one or more surface  
locations and caused to flow outwardly by the action of centrifugal force. A film  
may be a continuous annulus or may be a non-continuous arc at any radial location.  
45 The substrate may provide a plurality of films in dynamic contact with a rotating  
surface as hereinbefore defined.

35 For example processes requiring extended contact time may be carried out in  
continuous manner with use of a recycle of fluid exiting at the periphery of the  
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5 rotating surface towards the axis of the rotating surface enabling sequential passes of fluid across the surface. In continuous steady state operation an amount of fluid exiting the surface may be drawn off as product and an amount may be returned by recycle for further conversion with an amount of fresh reactant feed.

10 5 The process of the invention as hereinbefore defined may operated in a single or plural stages. A plural stage process may comprise a first pre-process stage with further post-process or upgrading stages, and may be carried out batchwise with use of a single rotating surface as hereinbefore defined or may be carried out in continuous manner with multiple rotating surfaces in series.

20 Second or more reactants may be added to the feed reactant as it passes from one rotating assembly to the next or be added directly to the rotating assembly anywhere between the axis of rotation or the exit from the assembly. In certain cases a multi-step process may be achieved by reactant addition or additions between the axis of rotation and the exit of a single rotating assembly to achieve more than one process step in a single pass. It is also possible to have different regions of the rotating surface at different temperatures and conditions and have different surface geometries as appropriate to the process needs.

25 20 It will be apparent that the process of the invention may be controlled both by selection of a specific rotating surface for the support element and by selecting process variables such as temperature, speed of rotation, rate of reactant feed, conversion time and the like. Accordingly the process of the invention provides enhanced flexibility in process control including both conventional control by means of operating conditions, and additionally control by means of rotating surface type.

30 40 The apparatus may further comprise any suitable control system. Such a control system may regulate the temperature or contact time of reactants by means of speed of rotation, rate of substrate feed and other process parameters to obtain an optimum result.

45 35 The apparatus as hereinbefore defined may comprise means for optimising process conditions. For example, means for imparting an additional movement to the rotating surface, and thus to the reactant, may be provided. Such movement could be in any desired plane or plurality of planes and preferably comprises vibration. Any suitable vibration means may be provided, such as flexible mounting of the surface or

5 off centre mounting, both inducing passive vibration or active vibration means, such  
as a mechanical element in contact with the rotating element and vibrating in a  
direction parallel to the rotating element axis. Preferably a passive vibration means is  
10 provided in the form of off centre mounting of the rotating element on its axis of  
5 rotation. Vibration may alternatively be provided by an ultrasonic emitter in contact  
with the rotating element for vibration in any desired plane or plurality of planes.

15 The rotating surface may have any shape and surface formation to optimise process  
conditions. For example the rotating surface may be generally planar or curved,  
10 frilled, corrugated or bent. The rotating surface may form a cone or be of generally  
frustoconical shape.

20 In one preferred embodiment the rotating surface is generally planar and preferably  
generally circular. The periphery of the rotating surface may form an oval, rectangle  
15 or other shape.

25 In another preferred embodiment the rotating surface is provided as the inner surface  
of a cone. The apparatus may comprise at least one cone and at least one other  
rotating surface or at least one pair of facing cones positioned so as to allow a two  
20 stage process with one or more reactants fed to each cone. Preferably product exits a  
smaller cone (or other surface of rotation) in a spray on to the surface of a larger cone  
30 (or other surface of rotation) by which it is at least partially surrounded and for the  
surface of which a further reactant is fed by feed means as hereinbefore defined, to  
allow mix of the product and reactant on the larger rotating surface. Preferably,  
35 means are provided such that the two cones counter rotate. Such an arrangement  
enhances mixing and intimate contact of the reactants and reduces the required  
physical contact time. Alternatively, means are provided such that the cones co-  
rotate or one is stationary.

40 In another embodiment, there may be provided two generally planar support elements  
mounted coaxially and generally parallel to each other on an axis of rotation. The  
facing surfaces of the support elements may be provided with at least one generally  
45 circular wall defined about the axis of rotation, and preferably a plurality of  
concentric walls, the walls being divergent with respect to the axis of rotation of their  
35 respective support element. The walls on one support element are positioned out of  
phase with the walls on the other support element so that the walls fit between each  
other when the support elements are brought close together. Reactant may be  
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5 supplied to a region within the innermost wall on one of the support elements. Upon  
rotation of the support elements, the reactant will tend to move along an interior  
10 surface of the divergent wall towards a region within the next wall on the opposed  
5 support element, and thence onto an interior surface of the said next wall back  
towards the first support element. The reactant may continue to move back and forth  
between the support members so as to progress in a zig-zag manner in a generally  
15 radial direction away from the axis of rotation along the interior surfaces of the  
intermeshed walls towards an outer collection point as described above. In this way,  
a compact reactor with a high first surface area is achieved, the first surface  
10 consisting of the interior surfaces of all the concentric walls. The support elements  
may rotate together in a given direction, or may rotate at different speeds in the same  
direction, or may rotate at the same speed or at different speeds in opposed  
20 directions.

15 A rotating surface of any shape and surface formation as hereinbefore defined may be  
provided with surface features which serve to promote the desired process. For  
25 example, the surface may be micro or macro profiled, micro or macro porous, non  
stick, for example may have a release coating, may be continuous or discontinuous  
and may comprise elements such as mesh, for example woven mesh, reticulate foam,  
30 pellets, cloth, pins or wires, for enhanced surface area, enhanced or reduced friction  
effect, enhanced or reduced laminar flow, shear mixing of recirculation flow in axial  
direction and the like.

35 In one preferred embodiment, mixing characteristics of the rotating surface are  
25 enhanced by the above features or the like provided on or in the rotating surface.  
These may be provided in any suitable regular or random arrangement of grids,  
concentric rings, spider web or like patterns which may be suitable for a given  
40 application.

30 Alternatively or additionally to any other surface feature, radially spaced pins in the  
form of circles or segments of circles may be provided.

45 In another preferred embodiment, a porous surface coating is provided, which aids  
processing of certain reactants. Such a coating may be provided in combination with  
35 any other of the aforementioned surface features.

50 Surface features in the form of grooves may be concentric or may be of any desired

5 radially spaced form. For example, the grooves may form "wavy" or distorted circles for maximised mixing.

10 Grooves may be parallel sided, or may have one or both sides which diverge to form  
5 undercut grooves or which converge to form tapered grooves. Preferably, the grooves are undercut to promote mixing.

15 Grooves may be angled to project towards or away from the axis of the rotating surface to enhance or reduce undercut or taper.

10  
20 Energy transfer means may be provided for the rotating surface or reactant or product as hereinbefore described. For example heating means may be provided to heat the reactant, for example, as part of the feed means. Additionally, or alternatively  
15 heating means may be provided to heat the rotating element in the form of radiant or other heaters positioned on the face of the rotating element which does not comprise the rotating surface for conversion. Preferably, radially spaced, generally circular  
25 radiant heaters are provided.

30 Any preferred cooling or quenching means may be provided in a suitable position to cool the reacted substrate. For example cooling coils or a heat sink may provide cooling by heat exchange, or a reservoir of quench may provide cooling or reaction termination by intimate mixing in the collection means.

35 For a better understanding of the present invention and to show how it may be carried  
25 into effect, reference shall now be made by way of example to the accompanying drawings, in which:

40 FIGURE 1 shows a spinning disc apparatus in schematic form;

30 FIGURE 2 shows a detail of a spinning disc having a central trough;

45 FIGURE 3 shows a detail of a spinning disc having an annular trough;

35 FIGURE 4 shows a number of spinning discs in schematic form and operatively arranged in series;

50 FIGURE 5 shows a number of spinning discs in schematic form and operatively



5 arranged in parallel;

FIGURE 6 shows two coaxial spinning discs in schematic form and provided with a  
10 pump unit for transferring product from one disc as feed to the second disc;

5 FIGURE 7 shows two rotating support elements with intermeshing concentric  
circular walls; and

15 FIGURE 8 shows a spinning disc provided with a rotary impeller.

10 Figure 1 illustrates a spinning disc apparatus of the present invention. The apparatus  
is enclosed in vessel (1) having at its axis a drive shaft (2) supporting a spinning disc  
20 (3). Feed means (4) provides reactant to an undercut annular trough (13) provided in  
the surface (5) of the disc (3) about its axis (6). Rotation of the disc (3) causes  
15 reactant to flow radially outwards, whereby it contacts the surface (5) of the spinning  
disc (3). Fluid is collected at the peripheral edges of the disc (3) by means of  
25 collection trough (7) and may be rapidly quenched by means of cooling coils (8). A  
skirt (9) prevents meniscal draw back of fluid contaminating the drive shaft  
mechanism. Inlet means (10) enable controlled environment conditions to the  
20 provided, for example a nitrogen atmosphere. Outlet vent means (11) enable the  
venting of atmospheric gases or gases evolved during operation. Observation means  
30 are provided by means of windows (12) to observe the progress of the conversion.

35 The apparatus of Figure 1 may be started up and operated as described in Example 1  
25 below. In the case that the process is an exothermic conversion, cooling coils (8)  
may be used to quench the collected product in the trough (7). The spinning disc (3)  
is provided with heating coils (not shown) which may be used to initiate or maintain  
conversion. The disc (3) or the reactor vessel (1) may be provided with a source of  
40 radiation, means for applying an electric or magnetic field and the like as described,  
30 at or above the disc surface (5) or at the wall of the reactor vessel (1).

45 In Figure 2 there is shown an axially located central trough (14) which is continuous  
and forms a well situated on the axis of rotation (6) of the rotating surface (5) of a  
disc (3). Rotation causes reactant (15) supplied by the feed means (4) to flow to the  
35 wall and form an annular film (16) within the trough (14). The annular film (16) then  
spills over onto the surface (5) of the disc (3) to form a film (17) on the surface (5).

5 In Figure 3 the trough (13) is annular and forms a channel co-axial about the axis of rotation (6) of the disc (3). Rotation assisted by the trough profile causes reactant (15) to flow into the trough (13) and to the wall thereof and form an annular film (16) within the trough (13) before spilling over onto the surface (5) of the disc (3) in the form of a film (17).

10 Figure 4 shows three discs (3) coaxially mounted on a drive shaft (2) which defines an axis of rotation (6). Each disc (3) has a central trough (13) into which reactant (15) may be fed, and a peripheral wall (18). Reactant (15) is supplied to the trough (13) of the topmost disc (3) by way of feed means (4), and then spreads out over the surface (5) of the disc (3). Product (19) is collected from the vicinity of the peripheral wall (18) by way of a pitot tube collector (20), which then feeds product (19) to the trough (13) of the next disc (3) down on the drive shaft (2). In this way, a process can be performed across a number of discs (3) in series.

15 Figure 5 shows three discs (3) coaxially mounted on a drive shaft (2) which defines an axis of rotation (6). Each disc (3) has a central trough (13) into which reactant (15) may be fed, and a peripheral wall (18). Reactant (15) is supplied in parallel to the trough (13) of each disc (3) by way of feed means (4), and then spreads out over the surfaces (5) of the discs (3). Product (19) is collected from the vicinity of the peripheral walls (18) by way of pitot tube collectors (20), which are also connected in parallel. In this way, a process can be performed across a number of discs (3) in parallel.

20 Figure 6 shows two discs (3) coaxially mounted on a drive shaft (2) which defines an axis of rotation (6). Each disc (3) has a central trough (13) into which reactant (15) may be fed by feed means (4) before spilling onto the surface (5) of each disc (3). A collector trough (21) is provided about the periphery of each disc (3) so as to collect product (19) thrown from the discs (3). An outlet from the upper collector trough (21) passes through a pump or extruder (22) before leading to the trough (13) of the lower disc (3) as feed means (4). This arrangement is suitable for use with viscous reactants and products.

25 Figure 7 shows a pair of planar rotating support elements (80, 81) coaxially mounted on an axis of rotation (6). The facing surfaces (82, 83) of the support elements (80, 81) are each provided with a plurality of concentric circular walls (84, 85, 86, 87),

5 with walls (84, 86) mounted on surface (82) and walls (85, 87) mounted on surface (83). The walls (84, 85, 86, 87) are divergent with respect to the axis of rotation of their respective support element (80, 81) and are positioned so that they mesh with  
10 each other when the support elements (80, 81) are brought together as shown.  
5 Reactant (15) is supplied to an interior region of wall (84) near surface (82) by a feed (4), and then proceeds to travel along an interior surface of wall (84) towards surface (83). When the reactant (15) reaches the top of wall (84), it spills over onto an  
15 interior surface of wall (85) on support element (81) and travels back towards support element (80) as shown. This process is repeated until the reactant (15) is thrown  
10 from the top of the outermost wall (87) into collecting means (not shown). By providing a convoluted surface along which the reactant (15) may travel, a very compact reactor may be obtained. The support elements (80, 81) may co- or counter-rotate, either at the same or at different rotational speeds.

25 15 Figure 8 shows a spinning disc (3) with a surface (5) mounted on a drive shaft (2) inside a vessel (1) and provided with a feed (4) for a liquid phase reactant, such as an organic prepolymer. A rotary impeller (70) is mounted coaxially with the disc (3) and close to the surface (5), and a surface (71) of the impeller (70) facing the surface (5) is provided with vanes (72). A gaseous phase reactant, such as nitrogen, is  
30 supplied to the vessel (1) through an inlet (10). Upon rotation of the disc (3), the liquid phase reactant moves from the centre of the surface (5) towards the periphery thereof as described above. When the impeller (70) is appropriately rotated on a drive shaft (74), the gaseous phase reactant is sucked into the space (73) between the impeller (70) and the surface (5) and moves towards the centre of the surface (5)  
35 against the flow of liquid phase reactant, thereby improving mass and/or heat transfer characteristics. Gaseous phase reactant and unwanted reaction by-products may be removed from the central region of the space (73) by way of a discharge pipe (75) to which at least a partial vacuum may be applied. A partial seal (76) in the discharge pipe (75) may be provided so as to control the rate of gaseous phase reactant and by-  
40 25 product removal.  
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**Example 1 – Polymerisation of ethylene using a catalyst coated disc**

Phillips catalyst was coated onto the surface of a spinning disc apparatus using methods as described hereinbefore. The coated disc was mounted in a spinning disc apparatus.

The spinning disc apparatus used is shown in diagrammatic form in Figure 1. The main components of interest being:

- i) Top Disc – A smooth brass disc of thickness 17mm and diameter 500mm capable of rotating around a vertical axis.
- ii) Liquid Distributor – A circular copper pipe of diameter 100mm, positioned concentrically over the disc, sprayed fluid vertically onto the disc surface from 50 uniformly spaced holes in the underside. Flowrate was controlled manually by a valve and monitored using a metric 18 size, stainless steel float rotameter. A typical fluid flow rate was 31.3cc/s.
- iii) Motor – A variable speed d.c. motor capable of rotating at 3000 rpm was used. The rotational speed was varied using a digital controller calibrated for disc speeds between 0 and 1000 rpm. A typical rotational speed was 50rpm.
- iv) Radiant Heaters – 3 radiant heaters (each consisting of two elements) spaced equally below the disc provided heat to the disc. The temperature was varied using a temperature controller for each heater. Each heater temperature could be controlled up to 400°C. Triac regulators were used to control the speed of the controller response. (These remained on setting 10 throughout the tests).
- v) Thermocouples and Datascanner – 16 K-type thermocouples embedded in the top disc gave an indication of the surface temperature profile along the disc radius. Odd numbered thermocouples 1 to 15 inclusive were embedded from underneath the disc to a distance 3mm from the upper disc surface. Even numbered thermocouples, 2 to 16 inclusive were embedded from underneath the disc to a distance 10mm from the upper disc surface. Each pair of thermocouple, i.e. 1 & 2 and 3 & 4 and 5 & 6 etc., were embedded adjacently at radial distances of 85mm, 95mm, 110mm, 128mm, 150mm, 175mm, 205mm and 245mm respectively (see Figure 3). The thermocouples were connected to the datascanner which transmitted and logged the data to the PC at set intervals using the DALITE Configuration and Monitoring

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Software Package.

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vi) Manual Thermocouple – A hand-held K-type thermocouple was used to measure the bulk fluid temperature on top of the disc.

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The rig was used in two arrangements. In one arrangement, feed was constantly added and the heated product was sent to the collection trough. In an alternative arrangement the rig was assembled with a recycle.

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10 The spinning disc apparatus of Figure 1 was started up and temperature and rotational speed adjusted. When steady stage was achieved gaseous ethylene was fed to the revolving catalyst coated disc surface at it axis. Product was withdrawn in the collection trough at the periphery of the disc. Analysis revealed the product was high grade polyethylene.

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Further advantages of the invention are apparent from the foregoing.

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## Claims

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CLAIMS:

- 10 1. A reactor apparatus including a support element adapted to be rotatable about an axis, the support element having generally opposed first and second surfaces, feed means for supplying at least one reactant to the first surface of the support element and collector means for collecting product from the first surface of the support element, characterised in that the first surface includes a trough into which the at least one reactant is supplied by the feed means.
- 15 2. A reactor as claimed in claim 1, wherein the axis is substantially parallel to a direction of action of terrestrial gravity.
- 20 3. A reactor as claimed in claim 1, wherein the axis is inclined with respect to a direction of action of terrestrial gravity.
- 15 4. A reactor as claimed in claim 1 or 3, wherein the axis is substantially perpendicular to a direction of action of terrestrial gravity.
- 25 5. A reactor as claimed in any preceding claim, wherein the trough is centrally located in the region of the axis.
- 30 6. A reactor as claimed in any preceding claim, wherein the trough is in the form of an annulus.
- 35 7. A reactor as claimed in any preceding claim, wherein the trough is centred about the axis.
- 40 8. A reactor as claimed in any one of claims 1 to 6, wherein the trough is not centred on the axis.
- 30 9. A reactor as claimed in any preceding claim, wherein the trough is undercut.
- 45 10. A reactor as claimed in any preceding claim, wherein a plurality of troughs is provided in the first surface.
- 35 11. A reactor as claimed in claim 10, wherein each trough has associated with it a feed means.
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12. A reactor as claimed in any preceding claim, wherein the trough is provided with a matrix which serves to assist reactant in the trough to rotate with the support element when this is rotated.

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13. A reactor as claimed in claim 12, wherein the matrix comprises a fibrous mesh.

15

14. A reactor as claimed in claim 13, wherein the fibrous mesh is made of a metallic material.

10

15. A reactor as claimed in claim 13 or 14, wherein the fibrous mesh includes a catalytic material.

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16. A reactor as claimed in any preceding claim, wherein the collector means includes a receptacle in the form of a bowl or trough at least partially surrounding the support element.

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17. A reactor as claimed in any preceding claim, wherein the collector means includes a deflector positioned about a periphery of the support element, against which product is thrown from an edge region of the first surface when the support element is rotating at an appropriate speed.

30

18. A reactor as claimed in any preceding claim, wherein the collector means is coated or otherwise provided with a catalytic material.

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19. A reactor as claimed in any preceding claim, wherein the collector means includes means for heating or cooling product in the collector means to a predetermined temperature.

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20. A reactor as claimed in any preceding claim, wherein the collector means is provided with feed means for adding a reactant to product collected therein.

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21. A reactor as claimed in any preceding claim, wherein the collector means comprises a wall disposed on a periphery of the support element and extending from the first surface.

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- 5 22. A reactor as claimed in claim 21, wherein the collector means further  
comprises a pitot tube which extends close to the first surface in the region of the  
wall and which serves to remove product from this region when the support element  
is rotated.
- 10 23. A reactor as claimed in any preceding claim, wherein the collector means is  
adapted at least partially to recycle collected product to the trough as feed reactant.
- 15 23. A reactor as claimed in any preceding claim, wherein the trough is coated or  
20 otherwise provided with a catalytic material.
24. A reactor as claimed in any preceding claim, including a plurality of support  
elements.
- 15 25. A reactor as claimed in claim 24, wherein the plurality of support elements is  
mounted on a single axis of rotation.
- 25 26. A reactor as claimed in claim 24, wherein the plurality of support elements is  
mounted on a plurality of axes of rotation.
- 20 27. A reactor as claimed in any one of claims 24 to 26, wherein product collected  
from a first support member is used as feed for a second support member.
- 30 28. A reactor as claimed in any one of claims 24 to 26, wherein feed means  
connected in parallel are used to supply reactant to each support element and in  
35 which collector means connected in parallel are used to collect product from each  
support element.
- 40 29. A reactor as claimed in claim 27, wherein a processing unit is provided  
30 between the collector means of the first support member and the feed means of the  
second support member.
- 45 30. A reactor as claimed in claim 29, wherein the processing means is a pump, an  
extruder, a heater or a heat exchanger.
- 35 31. A reactor as claimed in any preceding claim, wherein the feed means includes  
means for applying electromagnetic radiation or energy to the reactant.
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32. A reactor as claimed in any preceding claim, further including means for applying vibration to the support member.

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- 5 33. A reactor as claimed in any preceding claim, wherein there is further provided a rotary impeller or fan mounted close to the first surface and operable to generate a gaseous flow from a periphery of the surface towards a central region thereof, this flow being counter-current to a flow of reactant on the first surface.

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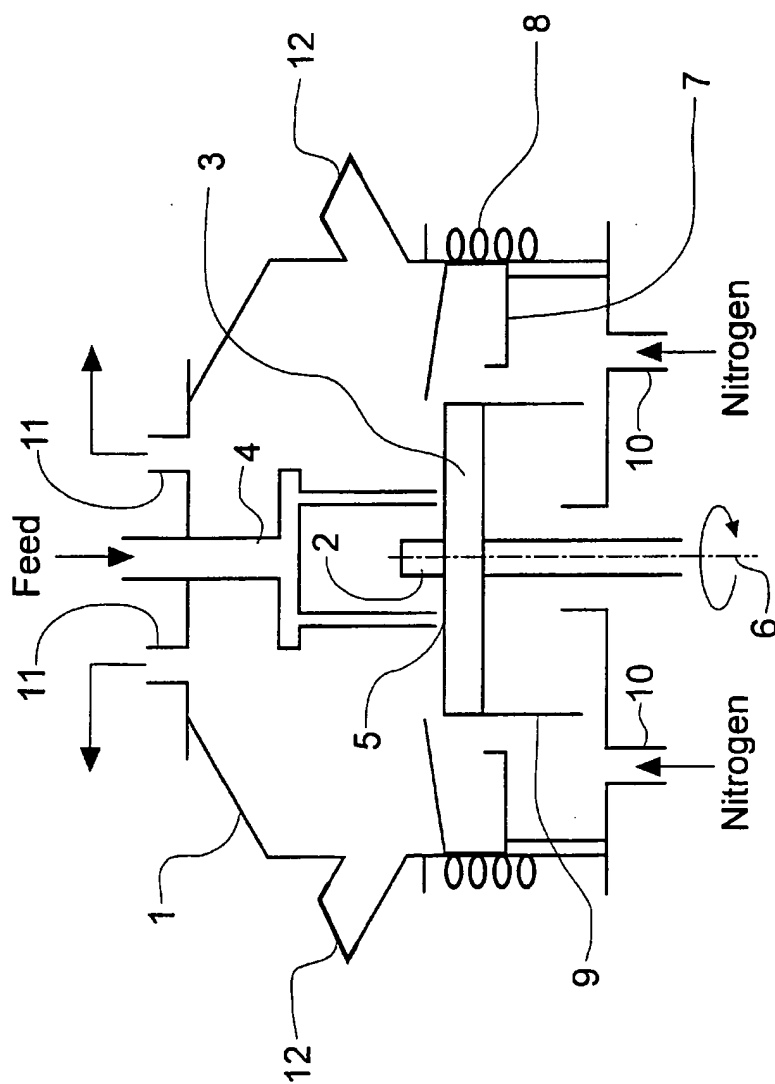


Fig. 1

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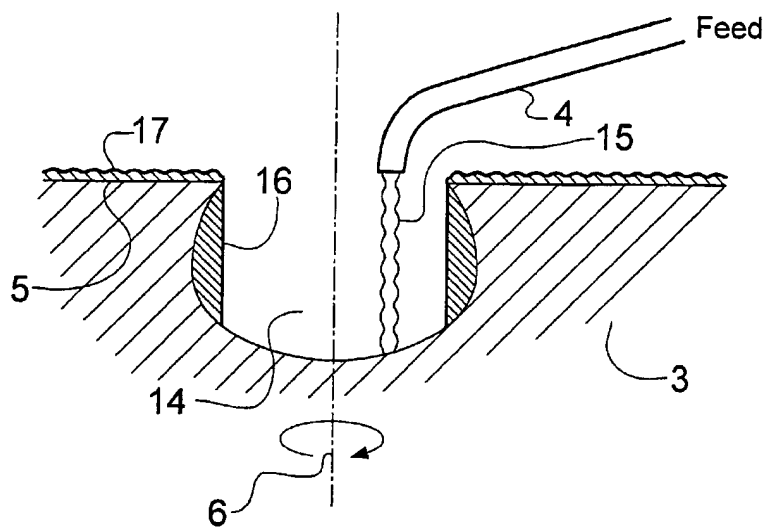


Fig. 2

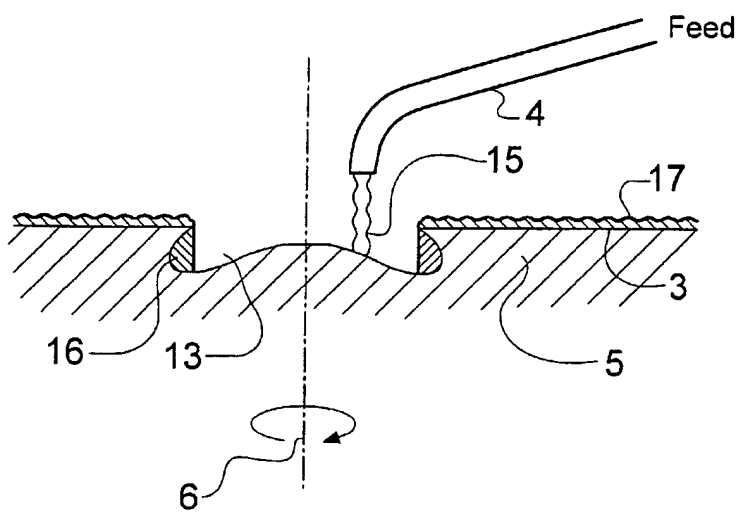


Fig. 3

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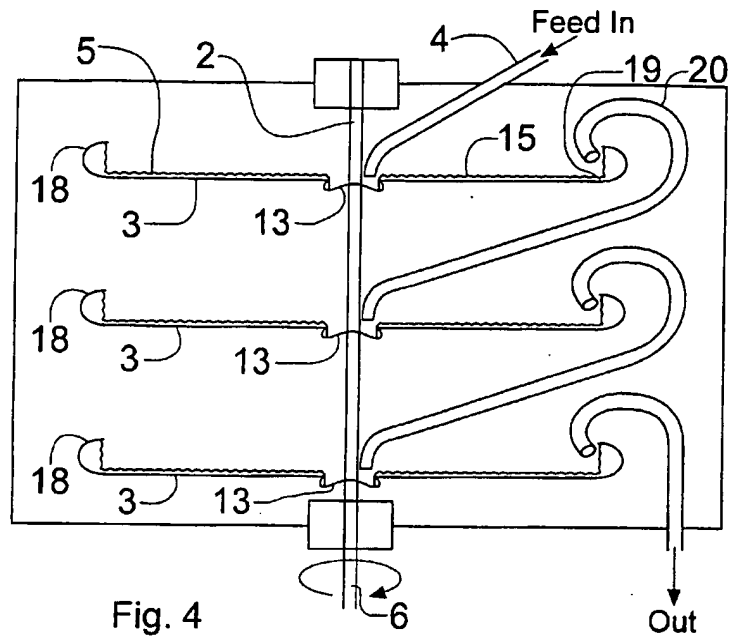


Fig. 4

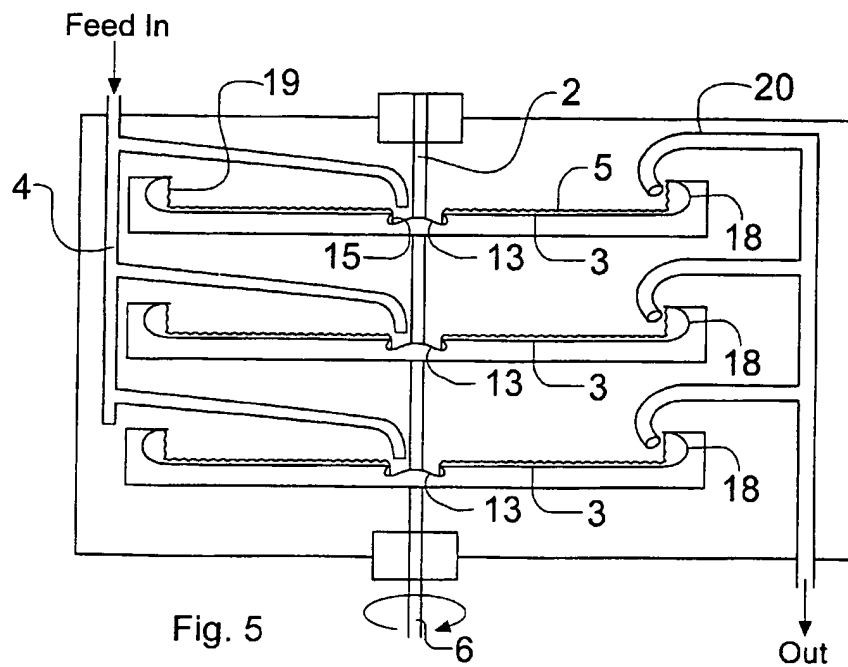
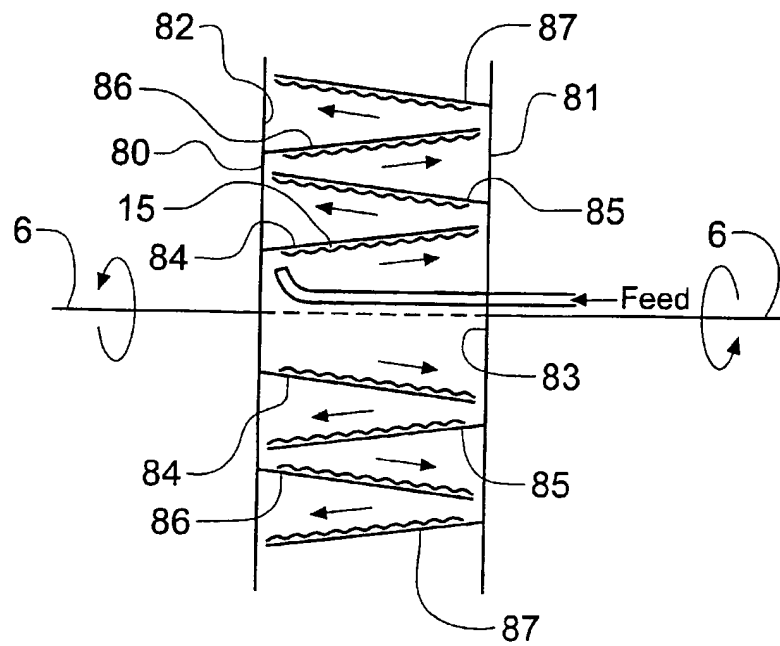
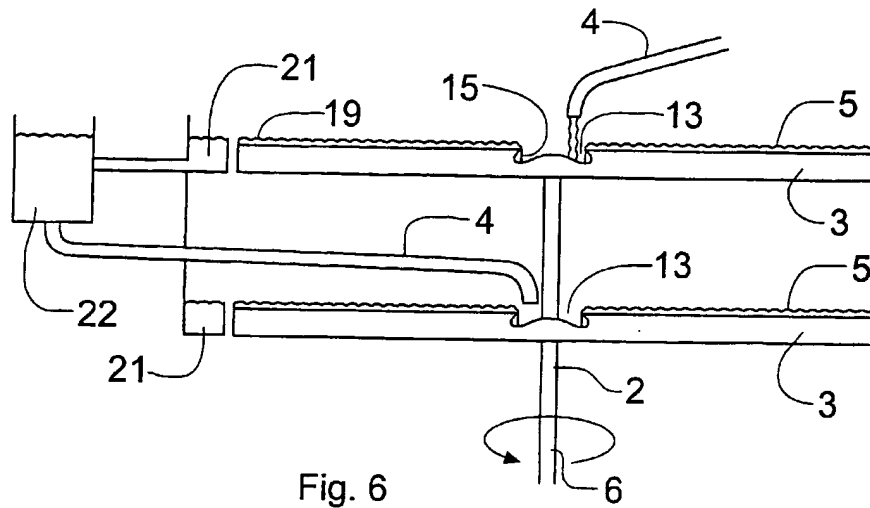


Fig. 5

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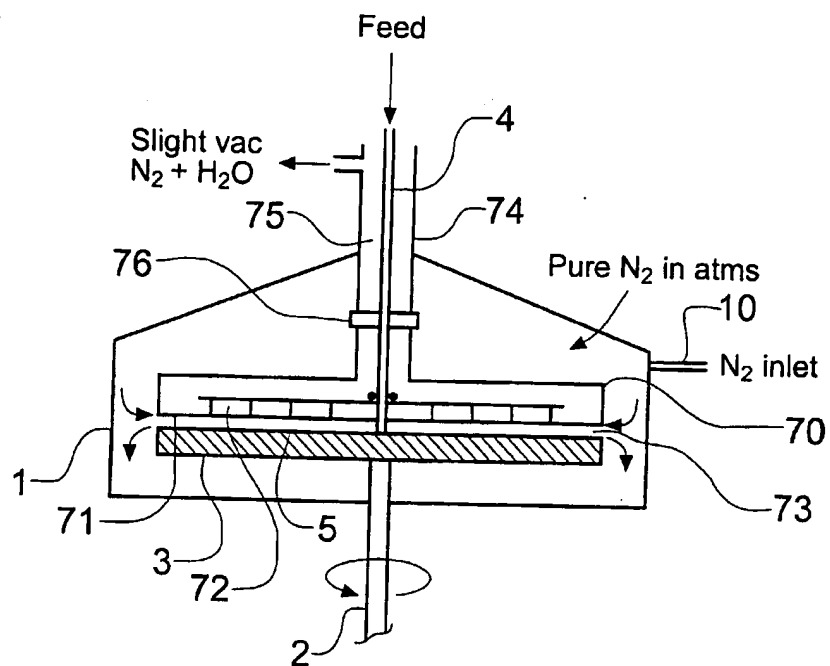


Fig. 8

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